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REQUIREMENTS FOR WATER FOR USE IN MIXING OR CURING CONCRETE.(U)
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REQUIREMENTS FOR WATER FOR USE IN MIXING OR CURING CONCRETE

TECHNICAL REPORT NO. 6-440

November 1956

Waterways Experiment Station
CORPS OF ENGINEERS, U. S. ARMY
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

PREFACE

The review of literature on quality of water for use in concrete making was begun in 1950 in connection with replying to a request from the Missouri River Division for information on the subject. A first draft of this report was submitted to the Office, Chief of Engineers, in November 1952. This first draft, with revisions suggested by the Office, Chief of Engineers, was distributed to the Corps of Engineers Division Laboratories in March 1953. The program of tests reported herein was authorized by the Office, Chief of Engineers, by first indorsement dated 18 November 1953 to a letter dated 8 October 1953, subject: "Methods of Testing Water for Mixing and Curing Concrete." The tests were conducted at the Concrete Division, Waterways Experiment Station, under the supervision of Messrs. H. K. Cook, T. B. Kennedy, B. Mather, and R. V. Tye; the literature survey was made and this report prepared by Messrs. Mather and Tye; the tests were performed by Messrs. Leonard Pepper, R. L. Curry, and E. E. McCoy.

This study was made as a part of Corps of Engineers Civil Works Investigation Item No. 600, "General Concrete Research."

CONTENTS

SUMMARY

Literature on the quality of water for mixing and curing concrete indicates that relatively few investigations on this subject have been conducted. It seems to have been generally agreed that water fit to drink was fit to use in concrete mixing, and even fewer limitations were applicable to curing-water quality. Tests were conducted by the Missouri River, South Atlantic, and Ohio River Division Laboratories, and the Waterways Experiment Station to determine the effects of pH values of water on the strength of concrete and the staining properties of elements found in water. It was found that various contaminants can render distilled water unfit for mixing or curing concrete. It is also indicated that pH does not provide a basis for specifying quality of mixing water. A procedure for evaluating curing waters for staining properties is presented in appendix A in which, for a preliminary evaluation, 3000 ml of the water are evaporated, and for a complete test 3 gal are evaporated. A digest of the literature is given in appendix B.

REQUIREMENTS FOR WATER FOR USE IN MIXING OR CURING CONCRETE

PART I: INTRODUCTION

1. Recognition of the need for laboratory testing procedures to provide information on the suitability of water proposed for use in mixing or curing portland-cement concrete for Corps of Engineers construction projects appears to have originated in the Central Concrete Laboratory of the North Atlantic Division. The 1942 Handbook for Concrete and Cement[10*] included in Part III - Miscellaneous, Chapter 1 - Water, an item entitled "Methods of Testing Water for Use in Mixing and/or Curing Concrete" which included procedures for the determination of staining, iron, sulfate, chlorides, and pH. When this volume was replaced in 1949 by the current Handbook[11] these procedures were included with suitable revisions in Part V: Water.

2. Experience developing in several parts of the United States in 1950 suggested that the requirements and methods then specified might not be adequate. At a conference of representatives of all Corps of Engineers Division Laboratories in December 1950 a request was made for data and recommendations. Data were received from three laboratories and were reviewed, together with available literature on the subject, by the Waterways Experiment Station.

3. In November 1952 a draft report, containing abstracts of all published comments on this subject that had then been located, a tabulation of the data submitted by the three Division Laboratories, proposals for revision of Part V of the Handbook for Concrete and Cement, and an outline of a proposed investigation, was prepared and submitted to the Office, Chief of Engineers. In February 1953 approval was received for the distribution of this draft, after revision, to the Division Laboratories for review and comment. In March 1953 this distribution was made, and comments were received from all laboratories. In October 1953 a

* Raised numbers refer to similarly numbered items in the list of references following the main report.

summary of these comments, a more detailed program of investigation, and new proposed revisions to the several Handbook items dealing with water were referred for approval to the Office, Chief of Engineers. Approval was received in November 1953.

4. The data submitted by the Division Laboratories, and those developed by the authorized investigation are summarized herein; the results of the literature survey as given in the 1952 report and as subsequently developed are given in appendix B.

PART II: RESULTS OF TESTS BY DIVISION LABORATORIES

Missouri River Division Laboratory Tests

5. Table 1 shows a comparison of results of two types of tests to determine the staining properties of water. Each sample was tested by CRD-C 401-48 "Method of Test for the Staining Properties of Water" and by a method developed by the Missouri River Division Laboratory and described in paragraphs 4-7 of CRD-C 401-54. The latter test method requires the use of a much larger sample than does CRD-C 401-48, and thus permits the detection of staining potentialities of lesser magnitude than does CRD-C 401-48.

Table 1

Comparison of Results Obtained with Missouri River Division Stain Test and with CRD-C 401-48

Lab No.	Dissolved Iron (Fe) Content, ppm	Amount of Staining: MRD Method*	Amount of Staining: CRD-C 401-48
49/11267A	0.07	Severe rust-colored stain	Moderate
49/11268B	0.02	Slight	None
49/11268C	0.05	Moderate	Moderate
50/3541A	0.06	Small amount of brown stain	Moderate
50/3541B	0.08	Small amount of rust-colored stain	None
50/3541C	0.32	Severe	Severe
50/5692A	0.04	Considerable brownish-black stain	None
50/5692B	0.06	Moderate rust-colored stain	None
50/5692C	0.06	Slight discoloration, mainly sediment	None
50/5692D	0.08	Slight discoloration, mainly sediment	Slight

* This method of test is described in CRD-C 401-54.

South Atlantic Division Laboratory Tests

6. The results of tests conducted by the South Atlantic Division Laboratory are presented in table 2. The stain tests were conducted according to CRD-C 401-48. In some instances water samples with relatively high iron contents produced only a moderate degree of staining.

Table 2

Results of Tests on Water for Use in Mixing and/or Curing Concrete Conducted by the South Atlantic Division Laboratory

Lab No.	Parts per Million Chlorides Cl	Sulfates SO_4	Iron Fe	pH	7-day Compr Str % of Distilled Water	Staining (CRD-C 401-48)
69/76	---	---	---	6.8	100	---
69/78	---	---	---	7.7	106	---
69/191	---	---	---	7.4	97	---
75/30	---	---	---	6.8	100	---
76/99	1	6	7	7.0	83	Severe
76/100	4	6	6	6.9	95	Severe
63/166	4	1	3.4	7.8	95	Slight
63/167	4	1	1.4	7.8	94	Slight
90/2	Trace	2	0.5	7.9	83	None
77/317	1	1	1.6	6.7	94	None
115/5	6	43	0.3	7.4	95	None
78/5	2	6	0.8	7.5	92	None
78/6	2	3	1.0	7.4	91	Slight
78/7	2	12	0.6	7.7	85	None
78/8	3	4	1.3	7.5	87	Slight
76/88	5	12	1.8	7.4	101	Moderate
76/89	2	4	4.1	7.6	99	Moderate

Ohio River Division Laboratories Tests

7. Table 3 summarizes the results of tests conducted by the Ohio River Division Laboratories on a number of samples of mixing water. It will be noted from examination of these data that the pH of four of the samples was less than 6 and that the results of other chemical tests varied over very wide ranges, yet only one of the samples (No. 12) appears to have had a significant effect on the compressive strength of the mortar in which it was used.

Table 3

Results of Tests on Water for Use in Mixing and/or Curing Concrete
Conducted by the Ohio River Division Laboratories

		Water Analysis, Parts per Million						Setting Time hr and min		Compressive Strength*		
Sample	pH	Total Solids	Suspended Solids	Iron in Suspended Solids	Iron	Chlor-ide	Sul-fates	DW**	Test Water	Using DW(A)	Using Test Water(B)	(B) as % of (A)
DW	7.0	0	0	0	0	0	0	----	----	----	----	---
1	3.9	---	--	--	--	35	292	6:40	6:30	2210	2135	97
2	7.2	---	--	--	--	42	15	6:40	6:20	2210	2115	96
3	6.65	271	--	--	12	--	2	6:40	6:50	2245	2290	102
4	7.7	---	--	--	Tr	--	10	6:40	6:30	2245	2345	104
5	7.7	---	--	--	Tr	--	Tr	6:40	6:30	2260	2180	96.5
6	7.9	---	--	--	--	--	20	5:45	5:35	3370	3190	94
7	7.7	---	--	--	--	--	10	5:45	5:35	3370	3125	93
8	7.0	---	--	--	--	--	10	5:45	5:45	3370	3140	93
9	8.0	---	--	--	Tr	--	180	5:45	5:50	1795	1845	103
10	3.7	---	--	--	10	--	220	5:45	6:20	1795	1765	98
11	7.8	---	--	--	--	--	20	5:00	5:00	2440	2215	91
12	5.95	115	65	6	11	9	7	5:00	5:20	2125	1720	81
13	7.4	---	--	--	20	--	20	4:30	4:00	2305	2260	98
14	4.55	---	--	--	--	21	83	4:40	4:40	2505	2690	107
15	7.6	---	--	--	Tr	--	47	5:00	5:00	2740	2595	95
16	6.8	163	35	16	16	10	Tr	6:00	6:00	2300	2315	101
17	6.5	152	13	2	2	8	3	6:00	6:00	2300	2320	101
18	6.5	14	--	--	1	--	Tr	6:40	6:45	2165	2185	101
19	7.3	552	40	7	8	--	53	6:40	6:15	2165	2450	113
20	7.4	35	--	--	Tr	--	Tr	7:15	8:00	2660	2610	98
21	7.1	305	--	--	12	12	38	3:00	5:00	1200	1170	98
22	6.85	228	--	--	3	5	13	7:00	7:00	2675	2625	98
23	7.35	206	--	--	2	4	Tr	7:00	8:30	2675	2470	92

* 2-in. cubes of 1:2.75 mortar made with standard sand, laboratory standard cement, and equal water content.

** DW = distilled water.

PART III: WATERWAYS EXPERIMENT STATION INVESTIGATIONS

Test Program

Purposes

8. The tests conducted at WES involved two programs. The first was designed to determine the effects on the properties of cement pastes and mortars of the use of distilled water buffered with a variety of chemical reagents to give pH values in the range 1 to 12. The second series was designed to determine the stain-producing properties of waters containing a variety of substances. Both programs had a second purpose of exploring the convenience and effectiveness of the test methods.

Materials

9. The paste and mortar tests were made using a cement manufactured at Birmingham, Alabama, that met the requirements for Type II and was designated RC-289. The mortars contained sand from Ottawa, Illinois, graded as required by CRD-C 406 (= CRD-C 116 = ASTM Designation C 87). The waters prepared for paste and mortar tests are listed in table 4.

Test methods

10. Pastes were tested for autoclave expansion by CRD-C 201 (Federal Spec. SS-C-158c). Mortars were tested for setting time by CRD-C 239 (former ASTM C 229), and for compressive strength by CRD-C 406. Staining tests were conducted according to CRD-C 401-52.

Results of Paste and Mortar Tests

11. The sixteen waters prepared for these tests were intended to include a wide variety of pH values. The reagents employed to prepare these waters included many that are not likely to be found in waters usually considered for use in concrete making. It is believed, however, that tests using these waters provided results that permit an evaluation of the significance of pH as a criterion of the quality of water for concrete making. An examination of the test results (table 4) indicates

Table 4

Tests on Pastes and Mortars at WES

Sample No.	Buffer Added	pH	Parts Buffer per Thousand	Water Added ml	Setting Time hr and min	Expansion %	Cement/sand %	Compressive Strength, psi 7 day	28 day	90 day
1	None	6.3	-----	230	3:45	0.08	27.8	1750	2865	4285
2	Citric acid and disodium phosphate	2.2	20.59 1.07	220	37:00*	**	25.3	†	†	†
3	Citric acid and disodium phosphate	3.0	16.70 11.02	220	24:20	**	27.3	†	†	†
4	Citric acid and disodium phosphate	4.0	12.91 20.67	217	22:10	**	26.2	†	†	†
5	Citric acid and disodium phosphate	5.0	10.19 27.62	215	22:10	**	26.6	†	†	†
6	Hydrochloric acid	1.1	10.15	233	3:05	0.08	27.6	2085	3290	4250
7	Glycocol, sodium chloride, and hydrochloric acid	2.0	7.51 5.85 10.15	225	3:05	0.07	27.8	2715	3840	4935
8	Potassium acid phthalate and hydrochloric acid	2.8	20.24 5.07	233	4:30	0.08	26.5	1910	3465	4960
9	Potassium acid phthalate and sodium hydroxide	5.0	20.24 2.00	230	4:19	0.06	29.5	1810	2860	4660
10	Carbonic acid and sodium bicarbonate	6.5	CO_2 1.05	228	3:50	0.07	27.3	1410	2815	3850
11	Primary potassium phosphate and disodium phosphate	6.8	13.61 26.81	236	8:10*	0.04	29.7	1405	†	†
12	Primary potassium phosphate and sodium hydroxide	6.8	13.61 2.00	228	8:10*	0.04	30.5	1490	2825	5765
13	Sodium borate	9.2	38.14	229	4:54	0.06	29.1	1255	2135	3425
14	Boric acid and sodium hydroxide	9.2	6.18 2.00	238	2:11	0.06	28.0	1275	2265	3425
15	Sodium bicarbonate and sodium carbonate	10.1	8.40 10.60	252	1:22	0.08	28.3	1130	1840	2615
16	Disodium phosphate and sodium hydroxide	11.5	26.81 2.00	231	5:35	0.07	27.2	1755	3175	4235

* Estimated.
** Paste failed to harden.
† Mortar disintegrated in curing water.

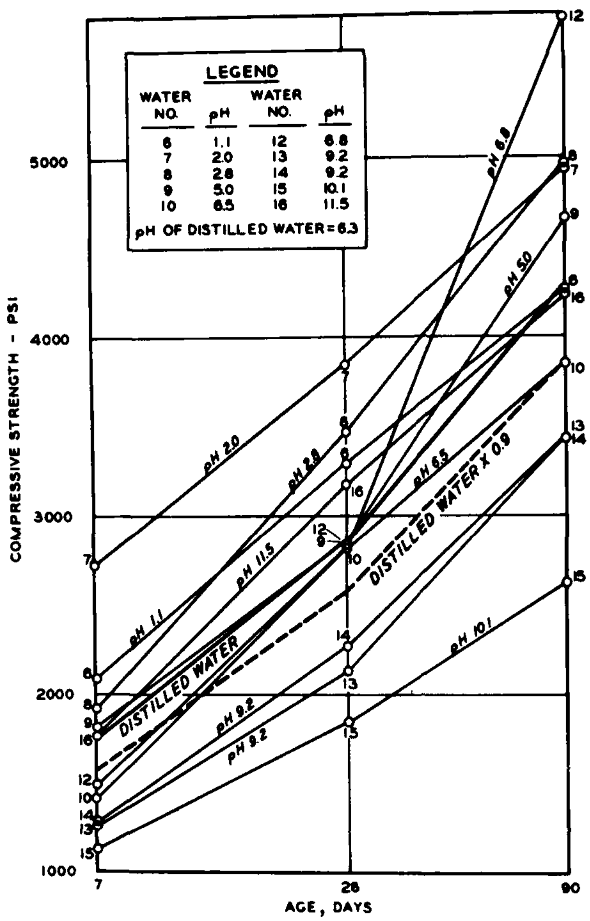

Fig. 1. Effects of various buffered waters on compressive strength of mortar

that the use of water samples prepared with citric acid and disodium phosphate effectively destroyed the cementitious action of the cement. None of the buffered waters caused an increase in autoclave expansion. Five of the ten buffered waters gave mortar strengths that were less than 90 per cent of the strength of mortars mixed with distilled water at one or more of the three ages of test. Samples 13, 14, and 15 were in this group at all three ages; sample 10 at 7 and 90 days, and sample 12 at 7 days only. It will also be noted (fig. 1) that mortars made with waters of the lowest and highest pH values, 1.1 and 11.5, have strengths close to that of mortar made with distilled water. Attention is also called to the mortar made with water 12 which showed a great increase in strength between 28 and 90 days. Fig. 2 suggests a possible relation between setting time and 90-day strength.

12. If cement hydration may be regarded as the breaking up by water of the tricalcium silicate component of the portland cement through the ini ial solution of the calcium oxide and later precipitation of calcium hydroxide, anything present in

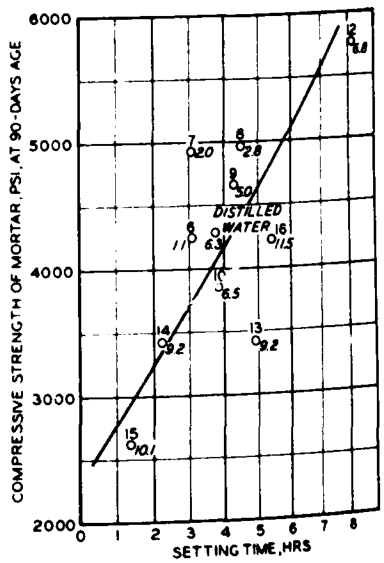

Fig. 2. Apparent relation between setting time and 90-day compressive strength of mortar

the water that would tend to increase the solution of calcium oxide, precipitate the calcium hydroxide, or both, would tend to increase the hydration rate. In general, water of a pH lower than 12 or buffered at a pH of less than 12, should increase the hydration rate. Conversely, if any component in the water should react to interrupt the process, the rate of hydration will decrease and perhaps in some instances, stop.

13. It was therefore expected that the time of set would vary directly with pH. The results do not show this relationship. However, 14 of the 16 solutions used were buffered solutions, and the strengths of the buffering action of each solution were not the same. The two unbuffered solutions (HCl, distilled water) indicate a possibility that the expected relationship is true. The most effective buffer solution was apparently the bicarbonate-carbonate solution, followed by the boric acid-NaOH solution (pH range from 9 to 10.5). The least effective buffer solutions were the citric acid-disodiumphosphate solutions followed by the mixed phosphate solution and the dihydrogenphosphate-NaOH solution (pH range from 2.2 to 10.5). The ineffectiveness of these solutions suggests the possibility that citric acid and phosphates may actually interrupt the process of hydration and be deleterious components in water. A tendency toward an inverse relationship was found between compressive strength and pH. In addition, those reagents that were considered as effective buffers for time of set were not found to give high strengths. Mortars made with water containing citric acid-phosphate groups, the least effective buffers, did not develop any strength at all. The mixed phosphate buffer gave very low strengths. The phosphate-NaOH buffer gave satisfactory strengths at 7 days and very high strengths at later ages (90 days).

14. The data indicate that the pH of mixing water is not in itself indicative of whether or not the water would prove to be satisfactory for making concrete. What seems to be important are the constituents of the water both individually and in combination.

Results of Stain Tests

15. Of the six contaminants tested, only two consistently produced

appreciable stain. Tannic acid, tested at 5, 30, 50, and 100 ppm, produced stain at all concentrations; the stains being more marked on the mortar specimens than on the plaster specimens. On the latter there was little difference in degree for the three higher concentrations. The stain produced by tannic acid is not evident on first evaporation of the water since the stain is not produced by the acid but by the breakdown of the acid on exposure to heat and light. Ferric chloride, tested at 0.25, 4, 20, and 100 ppm, also produced stain at all concentrations, more marked on the mortar than on the plaster specimens. The only other contaminant producing stain was carbon disulfide. It was tested at 0.04, 0.08, and 0.16 ppm. At 0.16 ppm it produced a very slight stain on the mortar specimen and none on the plaster specimen. At other concentrations it gave results similar to those of the other nonstaining solutions tested which included: sodium aluminate and calcium aluminate at 0.25, 1, 4, 20, and 100 ppm; and hydrogen sulfide at 0.02, 0.04, and 0.08 ppm. None of these produced a visible stain but gave evidence of a powdery deposit on the specimen surface; the amount of the deposit increased with increased concentrations of contaminant in the water.

16. The results described above were obtained using the test methods contained in the proposed revision of CRD-C 401 (see Appendix A). Much of the work done in the stain-test portion of the investigation was concerned with an attempt to devise modifications of the procedure described as "Complete Method" in CRD-C 401-52 and 54. No modification was found by which any significantly large proportion of the prescribed water sample could be caused to uniformly distribute itself over the surface of an inclined concrete specimen and then evaporate. The procedure finally adopted, while not having the apparent advantage of simulating the inclined downstream face of a dam, does provide for a known quantity of water to yield its stain-producing potential by relatively uniform evaporation over a given area.

17. As was noted in the discussion of results of tests with tannic acid, the degree of staining produced from certain contaminated waters depends not only on the concentration of the contaminant and the amount of water evaporated, but also on the degree of exposure to heat and light

for chemical effects other than simple evaporation.

18. The test results suggest that if 3 gal of water are used in the "Complete Method" using mortar specimens, comparable results may be obtained in the "Preliminary Method" using plaster specimens if 3000 ml are evaporated.

19. A particular instance of staining to which stain testing procedures would have been applicable is described below. The Ohio River Division Laboratories indicated that staining had occurred at Old Hickory Dam because of the prolonged use of curing water containing sulfides at very low concentrations. ORDL did not test the Old Hickory curing water for sulfides since facilities were not available to make such determinations at the job site and it was not practical to transport samples to the laboratory. The odor of hydrogen sulfide was detected and a sample of scale taken from the intake suckers in the well at Old Hickory was found to contain 15.6 per cent of sulfides. ORDL suggested that information on the composition of Cumberland River water in the vicinity of the Old Hickory Dam might be obtained from the Tennessee Board of Sanitation or the Tennessee Board of Rivers and Streams. Information from the Tennessee Department of Conservation was as follows:

> The sulfides present in the water at the dam site are largely due to the discharge of industrial waste into the river above the site. It has been estimated that the minimum flow of the Cumberland River will be 1000 cubic feet per second after Old Hickory Dam has been constructed. Based on this flow figure of 1000 C.F.S. the estimated average concentration of sulfides are calculated to be 0.04 parts per million hydrogen sulfide and 0.09 parts per million carbon disulfide. Of course natural aeration and oxidation make these figures hard to predict at any particular point. Sulfates will probably range around 55 P.P.M.

20. The Tennessee Department of Public Health reported as follows:

> We do not have any measurements of the concentration of sulfides in the river at Old Hickory; however, three values of hydrogen sulfide reported in the effluent from the DuPont plant in 1952 showed an average of 0.8 ppm. H_2S and an average of the three values of carbon disulfide equals 1.9 ppm. in the effluent.
>
> The total waste discharged from the plant varied between 25.5 to 29.5 mgd. with an average value of about 28 million gallons per day or 43 cfs. By calculations based on 1000 cfs. in the river and a ratio of one to twenty-three, the hydrogen sulfide content in

the river would be 0.035 ppm. H_2S and 0.083 ppm. carbon disulfide. The concentrations, of course, at 2000 cfs. would be exactly half of those listed for 1000 cfs. The above figures assume complete mixing with the total flow in the river at the time.

21. The application of external heat to promote evaporation is necessary to the performance of stain tests. Such heat may however promote chemical or biological activity, that normally would present no difficulty, to such an extent that serious interference results. In the developmental work reported here, green or brown stains due to accelerated growth of algae in the water were encountered in certain cases. Care should be taken in the interpretation of stain test results to exclude such extraneous effects.

PART IV: CONCLUSIONS

22. The test data obtained from all four laboratories suggest that a variety of still poorly understood factors may influence the effects of contaminants in waters used in concrete making. It appears clear that pH, per se, does not provide a basis for specifying quality of mixing water. Similarly the quantity of dissolved solids (expressed as parts per million) provides no basis, per se, for specifying quality of either mixing or curing water.

23. The procedures set forth in the proposed revision of CRD-C 401 are regarded as representing practical, workable, performance tests for determining staining tendencies of curing water. The proposed revision of CRD-C 400 summarizes the general conclusions of this report relative to "Requirements for Water for Use in Mixing or Curing Concrete."

24. The review of the literature, presented in appendix B, brings together the relevant published information and comments concerning effects of quality of water used in mixing concrete, and indicates both widespread unconcern and lack of precise data.

REFERENCES

1. Abrams, Duff A., "Tests of impure waters for mixing concrete." Jour. Amer. Conc. Inst., Proc., vol 20 (1924), pp 442-486; Structural Materials Research Laboratory, Lewis Institute, Chicago, Illinois, Bull. No. 12 (Sept. 1924).

2. American Association of State Highway Officials, "Standard method of test for quality of water to be used in concrete (designation T26-35)." Book of Standards.

3. American Concrete Institute, "Standard building code requirements for reinforced concrete (ACI 318-51)." Jour. Amer. Conc. Inst., Proc., vol 47 (April 1951), p 596.

4. __________, Manual of Concrete Inspection. 1955.

5. Austrian Board of Reinforced Concrete (Österreichisher Eisenbeton - Ausschuss), Specification for the Field Control of Concrete (Richtlinien für die Durchführung der Bankontrolle). Par. 3.

6. Bolomey, J., Resistance de quelque ciments a l'action de diverses eaux aggressives (Resistance of some cements to the action of various aggressive waters). L'ecole d'ingenieurs de Lausanne (Lausanne School of Engineering).

7. Bond, G. W., A Geochemical Survey of the Underground Water Supplies of the Union of South Africa. South African Department of Mines, Memoir 41, 1946.

8. __________, "Impurities in water in relation to concrete." Trans., South African Institution of Civil Engineers, vol 44 (1946), pp 197-200.

9. Concrete and Constructional Engineering, "Water for making concrete" (editorial). Concrete and Constructional Engineering (London), vol 42, No. 10 (October 1947); reprinted as Title 44-197 in Jour. Amer. Conc. Inst., Proc., vol 44 (Jan 1948), pp 414-416.

10. Corps of Engineers, Central Concrete Laboratory, Handbook for Concrete and Cement, Part III, Chapter 1 - Water, including: Methods of Testing Water. Mt. Vernon, N. Y., October 1942, pp 353-358.

11. __________, Waterways Experiment Station, Handbook for Concrete and Cement, Part V: Water, including items CRD-C 400 through CRD-C 406. Vicksburg, Mississippi, August 1949.

12. Fulton, F. S., "Deleterious substances in water used for concrete making." P. R. C. (South African Prestressed Concrete Development Group), vol 3, No. 10 (Dec. 1954).

13. French Specifications, No. 303/1941, p 18.

14. German Standard, Bestimmungen für die Ausführung von Bauwerken aus Eisenbeton (Building Regulations for Reinforced Concrete), Section A, II, par. 7, April 1932.

15. Grün, R., "Uber der einwerking einiger salse: Sansen und organischer substanze auf zement und beton" ("The effect of some salts: salts and organic substances upon cement and concrete"). Z. Angew. Chemie, vol 43 (1930), pp 496-500.

16. Joint Committee, Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete. 1940, p 204.

17. Kleinlogel, A., Influences on Concrete. Frederick Ungar, New York, 1950. Trans. by F. S. Morgenroth from the 1941 edition.

18. Leitch, R. D., and Calverley, J. G., Tests on the Effect of Acid Mine Waters on Various Cements. U. S. Bur. Mines, Rept. of Investigations 3487, Jan. 1940.

19. McCoy, W. J., "Mixing and curing water for concrete." ASTM Special Tech. Pub. No. 169, Significance of Tests and Properties of Concrete and Concrete Aggregates, Nov. 1955.

20. Mundt, H. W., and Flint, T. L., Investigations of Concrete and Concrete Making Materials Related to the Expansion of Canal Facilities Especially Third Locks. Final Report, United States Panama Canal Company, April 1952.

21. Office Général du Bâtiment et des Travaux Publics (Department of Public Works), "Project de norme relative aux agrégates et a l'eau de gâchage" ("Standard project concerning aggregates and mixing water"). Annales de l'Inst. Techn., No. 2, Paris (Mar.-Apr. 1936), p 67.

22. Plum, Niels M., ed., Concrete Manual. Bull. No. 39, Christiani and Nielsen, Copenhagen, Denmark, 1944.

23. Singleton-Green, J., Concrete Engineering. Vol 1, Charles Griffin & Co., London, 1933.

24. Spanish Regulations for the Design and Construction of Public Works, Cement and Lime Manufacture. Nov. 1948.

25. U. S. Bureau of Reclamation, Concrete Manual. 6th ed., U. S. Department of the Interior, Denver, Colorado, 1955.

APPENDIX A

CRD-C 400-56

REQUIREMENTS FOR WATER FOR USE IN MIXING OR CURING CONCRETE

Requirements

1. (a) **Mixing Water.-** Water used for mixing concrete shall be free of materials that significantly affect the hydration reactions of portland cement or that otherwise interfere with the phenomena that are intended to occur during the mixing, placing, and curing of concrete. Water that is fit to drink may generally be regarded as acceptable for use in mixing concrete. If it is desired to determine whether a water contains materials that significantly affect the strength development of cement, tests may be made according to CRD-C 406. Acid waters may prove acceptable but some such waters will produce significant increase in strength. Waters containing even very small amounts of various sugars or sugar derivatives should not be used. The harmfulness of such waters will be revealed in tests made according to CRD-C 406. Waters containing large amounts of dissolved sodium or potassium salts should not be used for mixing concrete made with reactive aggregate if no pozzolanic admixture has been specified when by so doing there is a danger of exceeding the condition for which low-alkali cement was specified. If the average of the results of tests, performed according to CRD-C 406, on specimens containing the water being evaluated is less tnan 90 per cent of that obtained with specimens containing distilled water, the water represented by the sample should not be used for mixing concrete.

(b) **Curing Water.-** Water used for curing concrete shall be free of materials that significantly affect the hydration reactions of portland cement or that otherwise intefere with the phenomena that are intended to occur during the curing of the concrete or that produce objectionable stain or other unsightly deposits on concrete surfaces. Objectionable staining is usually produced by the presence of organic materials such as tannic acid, or iron compounds such as ferric chloride. The degree of objectionableness of the staining produced as a result of the use of waters containing such materials for curing purposes depends on:

(1) The concentration of the stain-producing material in the water,

(2) The quantity of water evaporated per unit area of concrete surface,

(3) Degree of exposure of the surface to heat and light during evaporation,

(4) Importance of preventing discoloration of the surface.

The test methods outlined in CRD-C 401 are sufficiently sensitive to indicate significant stain when waters containing as low a concentration of ferric chloride as 0.25 ppm were tested in the quantities prescribed. Relatively low concentrations of stain-producing material in curing water may produce objectionable staining especially on concrete surfaces subjected to prolonged exposure to the evaporation of such water. In evaluating the results of staining tests and approving sources of curing water for use, care should be exercised to avoid condemning a source when the stain-producing materials were derived from pipes and tanks with which the water came in contact after being taken from its source, and to avoid creating unsatisfactory results by permitting the transportation and storage of otherwise satisfactory curing water by means that add stain-producing materials to it. Curing water intended for use on structures made with reactive aggregate and low-alkali cement but without a pozzolanic admixture should not contain sufficient amounts of dissolved sodium and potassium salts to endanger exceeding the condition for which the low-alkali cement was specified.

Methods of Test

2. The following methods may be used to test water samples:

(a) Staining properties (CRD-C 401),

(b) Iron in water (CRD-C 402),

(c) Sulfate ion in water (CRD-C 403),

(d) Chloride ion in water (CRD-C 404),

(e) Hydrogen-ion concentration of water (CRD-C 405),

(f) Effect of mixing water on compressive strength (CRD-C 406).

CRD-C 401-56

METHOD OF TEST FOR THE STAINING PROPERTIES OF WATER

Scope

1. This method of test outlines three procedures for evaluating the staining properties of water proposed for use in curing concrete. The Preliminary Method is intended for use in selecting sources that are worthy of more complete investigation. The Complete Method should be used to evaluate those sources that the Preliminary Method indicates to be promising. The Field Method should be used as a means of evaluating the source or sources finally selected for use.

Preliminary Method

Preparation of Test Specimen

2. At least 24 hr before starting the actual procedure, a neat cement or plaster-of-Paris specimen, approximately 4 in. square and 1/2 to 3/4 in. thick, shall be prepared. A white cement or plaster-of-Paris paste mixed to approximately normal consistency shall be compacted in a suitable mold and a deep concave surface formed in the top face by pressing a watch glass 4 in. in diameter into the specimen immediately after molding. The watch glass shall be removed and the specimen cured in the moist room for at least 24 hr. Upon removal from the mold the specimen shall be stored in the moist room until needed.

Procedure

3. The sample of water shall be vigorously shaken, and 3000 ml shall be measured out before settling occurs (Note).

Note.- It is important that the 3000-ml portion should include a representative amount of any sediment or precipitate in the original sample.

With continuous stirring to insure transfer of all sediment, the depression in the specimen shall be filled with a portion of the 3000-ml sample of water. The specimen shall be placed in an atmosphere favorable to evaporation (on a hot plate at low heat, or in a stream of warm air). As the water is evaporated from the specimen, (Note) more of the sample shall be added until the total 3000 ml has been transferred to the specimen and evaporated to dryness. Any iron or organic impurities possessing staining properties will be left on the specimen, producing a greater or lesser degree of stain. The specimen shall be visually examined and classified as showing: no stain, slight stain, moderate stain, or severe stain.

Note.- When staining due to iron compounds is going to occur to such an extent that moderate or severe stain is developed, the specimen will begin to show slight stain when only about 300 ml of water have been evaporated. A tentative evaluation may therefore be made at this point in the testing procedure if circumstances make such action desirable.

Complete Method

Apparatus

4. The apparatus shall consist of the following:

(a) Rack.- The rack shall support a water dispenser for each of the mortar test specimens. Provisions shall be made for supporting four 250-watt reflector-type industrial heat lamps approximately 15 in. from the surface of each mortar test specimen in a position such that the heat will be evenly distributed over the surface.

(b) Water Dispenser.- The water

dispenser shall consist of a glass or plastic carboy of at least 3-gal capacity fitted with a two-hole rubber stopper and glass tubing. One length of tubing shall serve as an air vent and shall be of a length sufficient to nearly reach the top of the inverted container. A short length of rubber tubing may be placed on the end of the glass tubing to extend the air vent above the surface of the water. A short length of glass tubing shall be inserted through the remaining hole in the stopper and shall be fitted with a length of rubber tubing to which a screw clamp is attached. The rubber tubing shall be positioned so that water drips on the mortar test specimen.

(c) **Fan.-** A small electric fan may be placed at the base of the rack to provide circulation of air over the surface of the test specimen.

Sample

5. The sample shall consist of 3 gal of water representative of the source under investigation.

Fabrication of Mortar Test Specimen

6. The mortar shall be proportioned and mixed[1] and the specimens cast as described in CRD-C 302, except that the edge of the specimens shall not be sealed, and the molds shall be underfilled so that the top surface of the finished specimen will be approximately 3/8 in. below the sides of the mold. The specimens shall be cured in laboratory air for 3 days prior to test.

Procedure

7. A 3-gal sample of the water that is representative of the source under investigation shall be placed in the carboy. The mortar test specimens shall be covered to a depth of approximately 1/8 in. with the water under test. The specimen shall be positioned under the heat lamps and the rate of flow adjusted to equal the rate of evaporation. The flow of water shall be interrupted and the specimen evaporated to dryness once each day. This procedure shall be repeated until the entire 3-gal sample has been evaporated.

Interpretation of Test Results

8. This method of test is designed to develop the staining potential of curing waters. The conditions of test are more severe than will generally be encountered in the field. Samples of water that do not produce a stain when tested by this method will not produce a stain under normal field use. Samples that produce a significant stain when tested by this method may or may not be suitable for use. If economic or other considerations indicate the need for more complete investigation, field tests should be conducted.

Field Method

Test Panel

9. A concrete test panel containing approximately 20 sq ft of area in its top surface, and of any convenient thickness, shall be cast in a location that receives maximum exposure to the sun. The panel shall be placed on a slight angle to facilitate runoff of the curing water.

Procedure

10. The test panel shall be cured for a period of not less than 28 days using the curing water proposed for use on the project. The flow of water over the test panel shall be sufficient

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[1] Hand-mixing or a suitable mechanical mixer may be substituted for the mixer specified in CRD-C 302.

to keep it in a wet condition, but run-off shall be kept to the minimum. The panel shall be inspected frequently during the test for evidence of staining.

APPENDIX B: REVIEW OF LITERATURE

1. The review of the literature on the quality of water that should be used for mixing or curing concrete indicated that this field has not been adequately investigated. The general opinion appeared to be that water fit for drinking is fit for concrete making and that in doubtful cases the engineer should resort to the mortar-strength test.

2. The earliest and still most complete investigation of the quality of water for concrete making was that reported by Abrams[1] in 1924. This report included the following:

> Water is one of the essential constituents of concrete; hence it is important to establish the effect of both quantity and quality of mixing water on the strength and other properties of concrete. Tests made in this and other laboratories have shown the effect of quantity of mixing water; the present investigation covers an experimental study of the effect of quality of mixing water.
>
> In many sections of the country the possibility of building concrete structures, especially concrete roads, may depend on the suitability of the local water which may be contaminated with various impurities; alkali water, bog water, and water containing sewage, mine pumpage, or other trade wastes are characteristic of many important industrial districts.
>
> A few tests from other sources have been reported on the effect of sewage on the strength and time of setting of cement; many tests have been made using sea water. Earlier tests were limited in number and scope; they were in general made on cement or sand mortar briquets; hence gave little direct information on the concrete-making quality of the waters. This appears to be the first comprehensive study of the effect of impure mixing waters on the strength of concrete.
>
> Sixty-eight separate samples of water were tested in two different series of investigations. Thirty-eight samples were collected from many sections of the country. Eighteen of the samples were from the Chicago District; the remaining 12 samples included distilled waters, synthetic sea water and solutions of common salt. In general the waters were of a nature which was believed to be unsatisfactory for mixing concrete. Parallel tests were made on several samples of clean, fresh waters. The samples may be classified as follows:
>
> Fresh, clean waters (in general potable);
>
> Minnesota bog waters;
>
> Sea and alkali waters;

Mine and mineral waters;

Waters contaminated with sewage and industrial wastes;

Solutions of common salt.

The tests described in this paper were confined to the use of impure waters in mixing concrete; the use of impure waters for curing concrete was not studied.

These tests were a part of the experimental studies of the properties of concrete and concrete materials being carried out through the cooperation of Lewis Institute and the Portland Cement Association at the Structural Materials Research Laboratory, Lewis Institute, Chicago.

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This report includes two series of tests and gives the results of about 6000 strength tests of portland cement concrete and mortar. Series 137 was confined to a 1:4 concrete using 50 separate samples of water; in Series 138, 18 separate samples were used in concrete of a wide range of mixes and consistencies. In both series concrete tests were made at ages of 3 days to 2-1/3 yr.

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The principal conclusions from these tests are:

(1) In spite of the wide variation in the origin and type of the waters used, and contrary to previously accepted opinion, most of the impure waters gave good results in concrete, probably due to the fact that the quantity of injurious impurities present was quite small. The following samples gave concrete strengths below the strength-ratio of 85 per cent which was considered the lower limit for acceptable mixing waters: acid waters, lime soak from tannery, refuse from paint factory, mineral water from Colorado, and waters containing over five per cent of common salt.

(2) The quality of a mixing water is best measured by the ratio of its 28-day concrete or mortar strength to that of similar mixes with fresh water. While the lowest permissible strength-ratio is a matter of judgment, waters giving strength-ratios which in general fall below 85 per cent should be considered unsatisfactory; if only isolated tests are made, 80 per cent should be the limiting value. The time-of-setting test appears to be an unsafe guide as to the suitability of a water for mixing concrete.

(3) Neither odor nor color are any indication of quality of water for mixing concrete. Waters which were most unpromising in appearance gave good results. It may safely be said, however, that any natural water which is suitable for drinking can be used without question for mixing concrete.

3. The next investigation was conducted by Leitch and Calverley[18] for the United States Bureau of Mines. These tests were conducted at

Pittsburgh in 1935. The performance of a variety of cements was compared after having been mixed with either Pittsburgh city water, dilute-acid mine water (400 ppm total acidity), or with highly acid mine water (8570 ppm total acidity). Seven cements were studied including three standard portland cements and one each of the following: high early-strength portland, "waterproof" portland, portland-pozzolan, high-alumina, and high-iron. A special quick-setting, acidproof, chemical cement was used as a reference in the test for durability on exposure but was not included in the strength-test series. Tensile strengths were determined at 7 and 28 days and specimens were exposed to immersion in acid mine water (8000 to 14,000 ppm total acidity). The tensile strengths at 7 days of mortars mixed with dulute-acid mine water were higher than those mixed with tap water. A similar relation existed at 28 days except for the high-alumina and the high-iron cements. The tensile strengths of cements mixed with strongly acid mine water were greater than those mixed with tap water except for the high-iron cement. A similar relation was found at 28 days except that one of the standard cements and the high-alumina cement also showed lower tensile strengths than when mixed with tap water. The exposure test lasted for a period of approximately 500 days. All slabs except that made with the special acidproof cement showed definite signs of deterioration. Only one slab mixed with acid mine water showed good acid resistance. It was made with portland-pozzolan cement. The only previous work referenced by Leitch and Calverley was that of Abrams.

4. In 1935, the American Association of State Highway Officials[2] adopted a "Standard Method of Test for Quality of Water To Be Used in Concrete" (Designation T 26-35). It provides that:

(1) Acidity and alkalinity or pH shall be determined; excessive acidity or alklainity or pH values less than 4.5 or more than 8.5 indicate that further tests should be made.

(2) Per cent total solids in 500 ml of water shall be determined by evaporation and weighing. The presence of organic matter is indicated by darkening of the evaporated residue when ignited and the amount indicated by the loss on ignition.

(3) If other tests are abnormal or the residue is large a determination of the composition of the residue may be made.

(4) A comparison oan be made of the effect of the water on

soundness, time-of-set, and compressive strength in mortar of a portland cement and the results when distilled water is used. Marked differences or a greater than 10 per cent difference in strength shall be sufficient cause for rejection.

5. A report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete,[16] issued in 1940, discusses water in section 204 of the "Recommended Practice" as follows:

> The mortar strength test is intended to assure the use of mixing water of satisfactory quality from the standpoint of concrete strength. The test may be waived...where the water to be used is of known satisfactory quality. Practical experience as well as results of laboratory investigations indicate, in general, that any water which can be safely used for drinking purposes will be satisfactory for use in concrete.

The report also includes in the "Standard Specifications" in sections 205-S and 206-S, the following:

> Water for concrete shall be clean and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.
>
> When subjected to the mortar strength test, the strength at 28 days of mortar specimens made with the water under examination and normal portland cement shall be at least 90 per cent of the strength of similar specimens made with the same cement and with water of known satisfactory quality.

6. The American Concrete Institute[4] Manual of Concrete Inspection dismisses the entire subject of the quality of water with these three sentences (p 78):

> Available water is rarely unsuitable for concrete-making; potable water is usually satisfactory. Ordinarily the fact that any harmful impurities -- alkalies, decayed vegetable matter, oil, sewage, or excessive amounts of silt -- are present will be known. Water of doubtful quality should be submitted for laboratory analysis or test; or, if time is available, specimens of concrete or mortar containing the water should be tested for comparative strength and durability with respect to control specimens made with water known to be satisfactory.

7. The material assembled by Prof. Kleinlogel[17] and published in German in 1941 became available in English translation in 1950. He provides the following comments:

> Mixing Water. This section discusses the effect of the properties of mixing water on the quality of concrete, while the effect of the quantity of mixing water on the strength of concrete is reviewed under Workability.

The Bestimmungen für die Ausführung von Bauwerken aus Eisenbeton (Building Regulations for Reinforced Concrete) of April 1932 specify in section A, II, section 7, ziff. 3:

> Any natural water can be used as mixing water unless it is strongly polluted. Salt water cannot be used as mixing water for high alumina cement.

The text of this regulation is far from being clear, because natural water varies so much. Such a short description cannot be sufficient. There are a number of cases where the water has to be tested before it can be used. Therefore it is of general interest to learn the result of those investigations which have been made on a broad scale using 68 different types of water and about 6000 mortar and concrete test pieces [1]. The strength was examined at different times varying between 3 days and 2-1/2 years. In most cases the mixture 1:4 was used, because it is the most common one. Nearly each kind of water, judged by its appearance, was just usable but not really very well suited for this purpose. These tests were compared with those made with pure water. The polluted water was considered acceptable if the reduction of the strength of the concrete was less than 15 per cent compared with the test pieces made with pure water. The tests confirmed that the properties and the quantity of the water are very essential in determining the strength and all the other properties of the concrete. The fact that even concrete made with polluted water proved satisfactory, was rather surprising. The compressive strength was reduced by more than 15 per cent only when the mixing water had an acid reaction: for instance, when it contained wastes from tanneries, chemical plants, or carbon dioxide, or more than 5 per cent sodium chloride. Sufficient strength was obtained when water was taken from gypsum mines or from streams which carry a great deal of sewage. Industrial wastes (from an oil refinery, brewery, soap factory, gas plant or malthouse) did not show any definite disadvantage. Sea water proved suitable as mixing water. Tests with the waste water from the huge abattoirs in Chicago showed surprising results. This water can be considered to be the dirtiest water in the world. It is so strongly polluted that it is covered by thick layers of scum and grease. The water has a dark color and an obnoxious odor. Nevertheless all the mortar and concrete test pieces showed, for any mixture, for any water-cement ratio and for any age, the same strength as if made with clean water.

Among the numerous results of the tests, which can be studied in detail in the original publication, the following are most important:

1. Neither the color of the water nor its odor gives a clue as to its usability as mixing water.

2. Contrary to the general opinion, many of the polluted types of water, used as mixing water, did not result in any

disadvantage to concrete. Obviously the pollution contained in the water was not concentrated enough or not efficient enough. In all these cases only water without any acid or with a low content of acid was used.

3. Marshy water is not considered usable as mixing water. Nevertheless samples mixed with it showed satisfactory strength.

4. Any water usable as boiler water can be used as mixing water without causing destruction of the cement or concrete.

The following impurities reduce the strength of the concrete by less than 15 per cent:

a) water containing sulphur as long as it contains less than 1 per cent SO_3. A content of 0.5 per cent SO_3 reduces the strength of the concrete by 4 per cent, a content of 1 per cent by more than 10 per cent;

b) water containing 0.15 per cent sodium and 0.15 per cent sodium chloride;

c) water from mines (with the exception of that from coal mines), and pump water from gypsum mines proved to be harmless;

d) waste water from slaughterhouses;

e) waste water from breweries, gas plants, malthouses and soap factories;

f) sea water which contains less than 3 per cent salt.

The following water is not usable:

a) sea water containing 3.5 per cent salt or more;

b) water containing 3.5 per cent sulphates in solution or more;

c) water containing more than 3 per cent sodium chloride (salt). Salt should not be used to prevent freezing of the mixture. The advantage of lowering the freezing point is offset greatly by the reduction of the strength of the concrete;

d) waste water from tanneries, chemical and galvanizing plants;

e) water containing sugar destroys the strength completely;

f) waste water from coke plants.

The results of all these tests are as important to concrete and reinforced-concrete structures as to highway construction. Many roads lead through areas with insufficient water supply or through arid areas. In these cases the problem of water supply is important. Naturally it must be stressed again that the danger of carelessness in the use of apparently polluted water must be avoided. It is urgently recommended that the purity of any doubtful water be tested before using it.

As emphasized already, it is not so much the pollution of the water as its acid content which has an unfavorable effect on the strength of concrete. The presence of certain acids in mixing water can be determined qualitatively by dipping litmus paper into it. If the paper turns red, it shows that the water contains acid and may under certain circumstances be harmful to concrete. A possible sulphur content, which is known to be very dangerous, is determined by using barium chloride. If necessary the water should be filtered until clear. The barium chloride solution combines with the sulphate to form a white precipitate of barium sulphate.

The best guarantee that water, to be used as mixing water, is either good or harmful, is given by tests carried out in a chemical laboratory.

The Richtlinien für die Durchführung der Baukontrolle (Specifications for the Field Control of Concrete) as formulated by the Österreichischer Eisenbeton-Ausschuss (Austrian Board of Reinforced Concrete) specify in section 3. Anmachwasser (mixing water):

> Mixing water should not contain humus, peat fiber and coal particles, and it should not be polluted by industrial wastes containing fat or acid. Water which contains acid, sulphur, or mineral springs cannot be used as mixing water. Mixing water must be tested for acid, by using litmus paper, and for its gypsum content, by using barium chloride. When these tests leave any doubt, an exact analysis must be made. Concrete test pieces, made with this mixing water, must be investigated as to whether this water has a harmful effect. In general, those quantities of harmful materials which are lixiviated from the surrounding soil and carried into the ground water, or which are in the precipitation water and may be dangerous to concrete, can, as ingredients of the mixing water, become dangerous only when their influence is increased by the continuous effect of the groundwater.

It makes a considerable difference whether the water is used as mixing water or if it flows around a concrete structure or penetrates it: it might be completely harmless in the first case, but extremely dangerous in the second.

8. In 1942 it was stated in the Handbook for Concrete and Cement[10] that:

> Water used in mixing should be clean and free from deleterious amounts of acids, alkalies, or organic materials. Generally speaking, water that is fit for drinking is suitable for mixing concrete. More specifically, if the pH of the water lies between 6.0 and 8.0, and the water is free from organic matter, it is safe for use in mixing concrete. Water for use in curing concrete should be tested to see that it will not cause objectionable stain...Water with an iron content less than 1.0 parts per million will not cause appreciable stain if free from organic materials. Higher iron

concentration, up to 2.0 parts per million, may cause only slight stain, but values higher than this will cause severe stain...

9. Plum,[22] in 1944, discussed water as follows:

Water. Most natural waters which are not contaminated by refuse from factories or the like can be used provided that they conform to the following requirements:[25]

The water must be reasonably clean and free from objectionable quantities of silt, organic particles, etc. If the suspended solids are found in excessive quantities, the water can only be used if they are allowed to settle in clarifying basins prior to use. The French regulations[21] require less than 2 g per liter for reinforced concrete and 5 g per liter for mass concrete.

With regard to chemical impurities the question is somewhat complicated and requires more chemical knowledge than is usually available at the working sites. Since the apparatus necessary to check the requirements stated there will also seldom be available, it must generally be recommended to have all suspicious water examined at an authorized laboratory.

For general orientation could be used the rule: That water giving less than 85% of the normal cube strength for pure water should commonly be rejected.

It must further be pointed out that tests must also be made with a view to the inactivity of the water to the reinforcement.

The temperature of the water must be above +5°C but not so high that the temperature of the paste exceeds +50°C as overstepping of this interval will unduly delay or increase the setting and hardening.[1]

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Water. The physical requirements have been stated and with regard to chemical impurities the question is divided in two, viz: First, the chemicals which absolutely must be avoided, as their presence means a danger to the very stability of the concrete, as humic acid and other organic acids; and, secondly, the chemicals which, although detrimental, only reduce the qualities slightly, as for instance chlorides, sulfates, etc. It is not practical to prescribe maximum permissible contents of these latter chemicals*, as it often can be necessary to use water containing them due to lack of any better and the procedure must therefore be in each case to determine the resulting reduction in qualities for instance by comparative cube compression tests,** and then adjust the

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* The French regulations[21] require less than 15 g per liter for R. C. and 30 g per liter for M. C.

** Water giving less than 85% of the normal cube strength for pure water must commonly be rejected.[1]

specifications (stresses) accordingly. In this connection attention is drawn to the fact that some of the impurities do not affect the properties until at rather late ages, for which reason tests must be extended over more than the normal period (to for instance 3 months).

The following common requirement figures may be used as a guide:

Table 26

pH value		6.8-7.6*
Sugar content		0% of cement
NaCl	2-3%	3% of cement
$MgCl_2$	1-2%	

The temporary hardness ($Ca(HCO_3)_2$) content and the gypsum ($CaSO_4$) content are of no importance.**

* 7.0 means neutral. Values below 7 indicate acidic character and values between 7 and 14 indicate basic character.

** The cement itself contains much higher quantities of CaO and $CaSO_4$ than will be contained in any even very unfavourable water.

10. A brief summary statement of the available information and opinions on the question of selection of water for concrete making was published in England and reprinted in the United States in 1948.[9] It reads:

> If a water is fit for drinking it is generally accepted as suitable for making concrete, but the standards of drinking water differ in various countries and the effect of the same water on different cements has been shown to be markedly different. By a sentence such as "The water shall be clean and free from deleterious materials" many specifications attempt to ensure that water used in making concrete is suitable for that purpose. Other specifications require that, if the water is not obtained from a source that has proved satisfactory, the strength of the concrete made with the available water should be compared with the strength of concrete made with water of known suitability, both concretes being made with the cement it is proposed to use in the works. American standards require that at the age of 28 days mortar made with ordinary Portland cement and suspected water shall have a compressive strength at least 90 per cent of that of mortar made with the same cement and water of known suitability. Although such tests may reveal early detrimental action on the setting of the cement, defects that may develop in the course of time and under conditions of exposure may not be discovered. The harmful effects of organic acids, for example, are not evident so soon as are those of mineral acids, while deleterious salts have a greater effect on strength at

an early age than at later ages. The enduring strength of concrete depends on the proper chemical reactions consequent upon the hydration of cement continuing for many years.

When a supply of proved suitability is not available, water may have to be taken directly from a natural source. Such water may be acid or alkaline, it may be hard or soft, or it may be contaminated with industrial waste or sewage. It is obviously undesirable to use mixing water which will interfere with the setting and hardening of cement, but the questions are What degree of impurity is permissible? and How will the impurity affect the concrete? It is known, for example, that sea-water at normal temperatures and with the concentration of salts (about 3-1/2 per cent) prevailing around the coasts of Britain does not appreciably reduce the strength of Portland cement concrete, although it may cause efflorescence and may lead to corrosion of reinforcement; that tannic acid and sugar in very weak solutions are harmful to concrete, as are most sulphate-bearing waters; that effluents from sewage works, gas works, paint works, and from the manufacture of artificial fertilizers can be detrimental, but effluents from oil refineries, breweries, and soap works may not be so; that waters draining off moorlands or from marshes and containing humic acid or free carbonic acid are harmful, although water containing dissolved carbonic acid is not; that chlorides may not be injurious but that all sodium salts are (the effect of the slight concentration of sodium chloride in normal sea-water may be negligible, but very salt water is harmful); and that soft water may produce a weaker concrete than does hard water, the magnesium sulphate in permanently hard water having little effect.

Knowledge of such tendencies is hardly sufficient, however, and more precise information is desirable. Much research, mostly unco-ordinated, has been carried out on this subject. The effects of temperature and the concentration of salts in sea-water have been investigated during the past hundred years, as has the effect on concrete immersed in sea-water of subsequent exposure to air or water. The damaging effect of pure water in making Portland cement concrete is also well known, although the records do not extend over so many years. The importance of the type of cement used is clearly shown in these investigations, because high-alumina cement is unaffected by being mixed with pure water but water containing salts should not be used with high-alumina cement.

In general, however, the available results of researches deal with specific cases of contamination, and apply to tests extending over limited periods. As has been emphasized previously in our pages in connection with cements, long-term tests are essential. It would be useful if authoritative data were available of the permissible limits of the impurities commonly found in water, and the limits should be determined for the various cements in use. It would also be useful if authoritative data were available of the permissible limits of the impurities commonly found in water,

and the limits should be determined for the various cements in use. It would also be useful if standard methods of testing were available by which impurities could be detected and their quantities determined. These tests should, so far as possible, be such that they can be quickly made on the site of the works to indicate whether the water is suitable, or definitely harmful, or whether testing in a laboratory is advisable before it is used. Visual inspection is useful, as the presence of some contaminations can be detected by the senses of sight or smell. Simple tests to detect acidity or alkalinity can be applied on the site, the easiest of which is the use of litmus paper. A more precise indication is obtained by noting the change in colour of water after which the addition of a few drops of a prepared dye to determine the hydrogen-ion concentration, the pH value. Neutrality corresponds to a hydrogen-ion value between 6 and 8; values below 7 indicate acidity and above 7 alkalinity. What is required to be established are the limiting values of hydrogen-ion for acidity and alkalinity for water to be used for making concrete with Portland cement. A range suggested in America is 4 to 8-1/2. Other chemical tests are available for the detection of sulphates, chlorides, and carbonates, but means are required of determining the quantities present and a knowledge of the amounts which may be harmful is desirable.

11. The preceding statement is the only item concerning quality of water given in the 1950 Index to the publications of the American Concrete Institute. Correspondence received from the Institute indicates that this statement, together with the references from various committee reports and standards, also quoted herein, are the only references to mixing-and-curing-water quality in ACI literature.

12. The U. S. Bureau of Reclamation Concrete Manual[25] refers to water as follows:

> Quality of Mixing and Curing Water.-Specifications require that mixing and curing water for concrete be reasonably clean and free from objectionable quantities of silt, organic matter, alkali, salts, and other impurities. Preparatory to its use in concrete, water from a stream carrying an excessive quantity of suspended solids should be allowed to stand in settling basins or be clarified by other means. A turbidity limit of 2,000 parts per million has been specified for mixing water. If clear water does not have a saline or brackish taste, it may be used...without further testing. Proposed curing water suspected of containing more than 1,000 parts per million of sulfate should be analyzed. Hard or very bitter waters are apt to contain high sulfate concentrations. Water from wells and streams in the arid Western States often contains dissolved mineral salts, chlorides and sulfates being the ones that are regarded with suspicion. The purest available sources should be used. All doubtful sources should be sampled...[and tested].

Tests by Abrams[1] show that the use of sulfate water in concrete produces little ill effect until an SO_4 concentration of about 1 percent is reached. For a concentration of 0.5 percent, the average reduction in strength was about 4 percent; a concentration of 1 percent produced a reduction in strength of more than 10 percent. Concrete made with sodium chloride (common salt) solutions showed significant reductions in strength at ages greater than 7 days, for all concentrations. Five percent of ordinary salt reduced the strength about 30 percent. A highly carbonated mineral water containing only small quantities of sulfates and chlorides gave a strength ratio as low as 80 percent.

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Sampling and Analysis of Water and Soil.-Steps should be taken in the field to ascertain whether the water in the vicinity meets specification requirements applying to its use in mixing and curing of concrete...also whether the soil or water with which the concrete will be in contact contains harmful sulfate concentrations...

If the available water is of questionable quality for the intended use, a sample should be sent to the...laboratory, together with a complete sampling report, for a determination of quality...

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Water.-...After construction is under way and the source or sources of water have been established, regular testing and inspection is not necessary unless the water becomes contaminated with excessive amounts of suspended matter because of abnormal stream flow, or with objectionable concentrations of soluble salts during dry seasons. If the water is clear and does not have a brackish or saline taste, testing is unnecessary.

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Sampling Soil and Water for Chemical Analysis (Designation 3):

1. General. - Prior to construction, definite knowledge concerning alkali concentrations in both soil and water is essential to permit selection of the most suitable type of cement...It is also important to know the quality of water to be used for mixing and curing concrete. This information can be obtained by chemical analyses, made in the...laboratory, of carefully collected samples...When collecting samples, the following considerations should be borne in mind...: (g) Samples of the water proposed for use in the manufacture or curing of concrete should be taken from the source from which water for concreting operations will actually be obtained. The water should be allowed to flow freely for at least 10 minutes and the containers should be rinsed with the water before the sample is collected.

2. Sampling, Shipment of Samples. - ...Water samples could

consist of at least 1 pint and should be shipped in clean pint fruit jars tightly capped...

13. A letter (18 September 1952) from Mr. Walter H. Price, Chief, Engineering Laboratories Branch, U. S. Bureau of Reclamation, Denver, Colo., indicates that in future editions of the Concrete Manual there will most likely be a further statement to the effect that curing water should be of better quality (containing lower concentrations of soluble sulfate salts) than the mixing water to avoid sulfate concentrations from accumulating on the outside surface of the concrete. He also notes that the references in the Manual are the only published statements on this subject by the Bureau of Reclamation.

14. The ACI Building Code includes as Section 206 "Water" the following: "(a) Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalies, organic materials, and other deleterious substances."[3]

15. A report issued in 1952 by Mundt and Flint[20] regarding materials for use in concrete work in the Panama Canal Zone included a consideration of water. This report covers the investigation of four sources of fresh water considered for use in the project, and two sources of sea water which were included primarily for reference control purposes. Previous service records indicated that two of the fresh-water sources were entirely satisfactory for use in mixing and curing concrete. The other two sources, for which service records were not available, were investigated in an attempt to locate a more economical supply. The test results indicated that all of the four sources investigated were satisfactory for use as mixing water. Tests to determine the suitability of these waters for curing concrete were not made; however, it was felt that waters that are satisfactory for mixing are obviously suitable for curing purposes.

16. F. S. Fulton[12] in 1954 prepared a discussion of deleterious substances in water used for making concrete that, although specifically directed to problems in South Africa and particularly applicable to prestressed concrete, is nevertheless rather more complete than most discussions of the subject. Fulton makes the important point that it is quite possible for the deleterious effects of impurities in the mixing water to

supplement deleterious effects of undesirable materials present in other constituents of the concrete, particularly the aggregates. Therefore, an aggregate that may safely be used with pure water might be undesirable when used with contaminated water. He gives as an example: The strength of an aggregate containing iron sulfide might be satisfactory when pure water is used but unsatisfactory when sulfate-bearing mixing water is used. He makes a further point that the effect of deleterious substances in water may be quite different depending upon the type of cementitious medium used in the concrete, pointing out that the effect of a given impurity in the water may be quite different in concrete made with portland cement as compared with that in concrete made with aluminous cement or pozzolanic cement. Fulton cites the conclusions of the work reported by Abrams in 1924[1] and then quotes G. W. Bond,[7] who had studied the water supplies of South Africa, as having concluded that with the possible exception of some highly mineralized water found in two limited regions, the majority of the brackish water of South Africa could be satisfactorily used in concrete. Fulton makes the point that water which might be destructive to hardened concrete might be satisfactorily used for mixing water and states, as have many others, it can be assumed that "any water which is suitable for drinking can be used without question for the manufacture of concrete." He refers to the use of strength tests to evaluate water not previously used, and points out that since the detrimental effect that it is desired to avoid may develop over a long period of time, it would seem unwise to rely entirely on mortar tests at early ages. He recommends the making of chemical analyses but notes the lack of criteria with which to interpret the results. He calls attention to the fact that in South Africa the waters fall into three classes: (1) pure water containing not more than 15 parts per 100,000 of dissolved solids; (2) carbonate water containing up to 80 parts per 100,000 of dissolved solids; and (3) highly mineralized water containing from 100 to 1000 parts per 100,000 with abundant chlorides and sulfates. He suggests that with the exception of the more acid water of Group 1 and the concentrated water of Group 3 the rest are suitable for concrete work unless polluted. He reviews the results reported by Abrams,[1] Kleinlogel,[17] and others regarding the effects of contamination by sulfates, chlorides, carbonates, and other substances, and concludes that the presence of excess sulfates is not in itself a sufficient basis for rejection of mixing waters. He also concludes that it would probably be desirable to follow the Spanish specification[24] and reject water containing more than 1000 parts of sodium and magnesium chloride per 100,000 in water used for reinforced concrete; that water containing carbonates is presumably not harmful; that water containing more than 300 parts per 100,000 of organic material probably should be rejected, and suggests that the possibility of impurities in water contributing to stress corrosion of steel should be fully investigated before an impure water is permitted in concrete to be prestressed. He states, "Pending further information it would be extremely unwise to use sea water for prestressed concrete work; to use any water containing high proportions of chloride; or to permit the addition of calcium chloride...but in general, if the particular impurity has even a mildly corrosive action on steel, the water should be rejected as unsuitable for use in prestressed concrete."

17. W. J. McCoy[19] summarized available data in a paper which he abstracted as follows:

> The quality of cements and aggregates are often exhaustively investigated but little attention is usually given to the requirements for the water to be used with the cements and aggregates. This paper is primarily concerned with the significance of tests of various types of waters for mixing and curing concrete and makes no attempt to include the effect of unit water content on the various properties of concrete.
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> A popular criteria as to the suitability of water for mixing concrete is the classical expression "If water is fit to drink it is alright for making concrete". This does not appear to be the best basis for evaluation since some waters containing small amounts of sugars or citrate flavoring would be suitable for drinking but not mixing concrete and, conversely, not all water unsuitable for drinking is unsatisfactory for use in concrete.
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> The significance of the information presented indicates that any naturally occurring water suitable for drinking purposes can be used as mixing water for concrete, and that most naturally occurring waters ordinarily used for industrial purposes are satisfactory. Many waters which upon casual examination would be judged to be unsuitable because of color, odor or contamination with impurities as in the case of marsh water, alkaline sulfate

waters, and water containing industrial wastes would be found to be satisfactory when tested in mortar or concrete since in many instances the strength would be greater than 85 to 90% of the strength of comparative specimens made with pure waters. In the case of sea water, a strength reduction ranging from 8 to 15% can be expected depending on job conditions, however, it is not generally recommended for use in reinforced concrete.

There are two primary considerations with regard to the suitability of water for curing concrete, one is the possibility that it might contain impurities that would cause staining and the other is that it might contain aggressive impurities that would be capable of attacking or causing deterioration of the concrete. The latter possibility is very unlikely especially if water satisfactory for use in mixing concrete is employed. Organic matter or iron in the curing water can cause staining or discoloration of concrete but this is rather uncommon especially where a relatively small volume of water is used, however, performance tests will determine if a water possesses any potential staining qualities.